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Control of Tobacco Wildfire

SECOND REPORT

TOBACCO FREE OF WILDFIRE ON SOIL FORMERLY CONTAMINATED WITH THE DISEASE
The disease disappears in soil through crop rotation and the decay of infected tobacco waste.

The Pennsylvania State College
SCHOOL OF AGRICULTURE AND EXPERIMENT STATION
State College, Pennsylvania

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LANCASTER COUNTY and parts of adjoining counties in Pennsylvania comprise one of the principal regions engaged in the culture of cigar-leaf tobacco. There are approximately 7000 growers. In this region, wildfire leaf spot caused by *Bacterium tabacum* (Wolf and Foster) has become an unusually difficult problem. The severity of damage is discouraging many growers and the crop acreage seems destined to decline unless the handicap of disease loss is removed.

The commonly recommended mode of control, based upon the maintenance of disease-free seed beds, has not been wholly successful in preventing the development of wildfire in Pennsylvania tobacco fields, although this measure apparently has been quite effective in certain other tobacco regions, notably in the Connecticut Valley and Wisconsin. In Maryland, it is difficult to prevent wildfire in seed beds; but leaf-spot results in no decided reduction of value there, since the tobacco is cut up in processing. In the case of cigar leaf, however, freedom from defects or any tendency to shatter is very important, especially if the product must be sold in a competitive market.

Causes of Leaf-Spot Damage

Leaf-spot damage to tobacco in Pennsylvania is nearly all parasitic, with *Bacterium tabacum* as the chief cause. There are a number of injuries of minor importance, such as (a) the necrosis or "firing" of leaf areas following severe mosaic infection; (b) similar effects caused by drought and potash hunger; (c) a limited amount of spotting caused by *Macrosporium tabicinum* (Ell. and Ev.) ; (d) ring-spot caused by a virus, observable each year but usually unimportant; and (e) a slight amount of non-parasitic spotting which develops on areas of occasional maturing leaves where the lower epidermis is turned to the sun after a period of rain. A feature distinguishing this last type of leaf-spot is that it begins on the lower epidermis and frequently does not extend through to the upper side of the leaf.

Angular Leaf-spot. Isolation and infection studies with bacterial organisms from various types of spots have thus far shown Angular leaf-spot, *Bacterium angulatum,* apparently absent, although reports of the presence of this parasite in Pennsylvania (4, 5, 6) have been made on the basis of disease symptoms observed in the field. Possibly these reports are erroneous, since lesions with dark color and angular outline occurring on old leaves near the soil often have a close resemblance to angular leaf-spot but are actually caused by the wildfire organism. Lesions resembling the small, black angular spots that distinguish *Bacterium angulatum* infections on seedlings have been observed in a few instances, but they were not definitely determined to be caused by this organism. Cured tobacco leaves with disease lesions have been collected in different localities and placed in experimental beds of seedlings, but all resultant new infections have always been characteristic of wildfire.

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"Black-fire" or "Rust." The general leaf-spotting, supposedly non-parasitic, said to be caused by wet weather and sometimes referred to as "black-fire" (19) including what farmers commonly regard as "rust"[2] is essentially a manifestation of wildfire, according to recent investigations in Pennsylvania. There is commonly much speculation among farmers and others interested in tobacco whether given cases of leaf-spot damage are caused by wildfire or "rust."

The spot considered as typical wildfire is distinguished by a small, tan, central area of dead tissue surrounded by a definitely limited yellow halo in which the chlorophyll has broken down. Fully as common on the tobacco leaf, however, is a larger, reddish-brown, somewhat zonated spot developing without a halo and long known to farmers as "rust" (Fig. 1). This is particularly associated with rainstorms and is marked by a briefer period of development than the disease which is described as "typical wildfire." It may attack tobacco at various stages of growth, but most commonly at maturity. Most tobacco growers regard "rust" as caused by wet weather. The question of whether certain aspects of rust may be physiological or non-parasitic has been discussed by plant pathologists (9, 19).

Bacteria generally are present in these "rust" spots in great numbers and cultures of wildfire have been obtained in such a large proportion of cases that it may be questioned whether any of them are physiological in their primary origin. If physiological factors are operating, the effect probably is a modification in the development and character of a lesion caused by the parasite. The distinctive feature appears to be that the host tissue dies so promptly that the halo never is discernible. Furthermore, it is apparent from field observations that "rust" always is associated with the typical wildfire spot distinguished by the yellow halo, or with soil that has been infested by *Bacterium tabacum.* In a locality where there is rather general wildfire infestation, the situation is likely to be confusing; but when disease-free plants are grown where wildfire has never occurred, rainstorms or extended wet weather have not been observed to cause "rust," or any disposition to leaf-spotting.

Attempts were made to produce physiological spotting by keeping the soil very wet for a period just prior to maturity of the tobacco. No spots resulted that resemble "rust." A garden sprinkler was placed in plots of tobacco and water permitted to play upon the leaves for a period during cloudy weather. This, likewise, was without effect except where the wildfire organism was known to be present; the spots resulting developed rapidly, appearing within 3 or 4 days after the sprinkling. They were reddish-brown, lacked haloes, and in all respects were typical of "rust." These spots all yielded cultures of *Bacterium tabacum.*

Clayton (9) is of the opinion that the major injurious effect of rainstorms on wildfire is not the dissemination of the bacteria themselves but the breaking down of the resistance of the tobacco plant; and that driving rain causes the water-soaking of leaf areas, through which the bacteria spread rapidly. Without the water-soaking, a much longer period is required for *Bacterium tabacum* to cause a relatively small lesion, and during the longer period the toxin produced by the parasite has time to spread beyond the region of invasion, destroy

[2] The term "rust" may be applied by farmers to various disease lesions occurring on the tobacco leaf.

FIG. 1. A TOBACCO LEAF SHOWING TWO TYPES OF WILDFIRE SPOTS

a and *b* are typical wildfire spots, with the tan central area surrounded by the halo. *c*, *d* and *e* are the so-called "rust" spots, which are reddish-brown and develop in a few days after rainstorms, usually when the tobacco is maturing. The type represented by *a* and *b* has a longer period of development and is more common on immature leaves. Both types are caused by the wildfire organism, *Bacterium tabacum*.

the chlorophyll and make the characteristic halo apparent. Hence, the leaf spot called "rust" is but a manifestation of wildfire.

Early Outbreaks of "Rust." Since wildfire has been shown to be the cause of essentially all important leaf-spot damage to tobacco in Pennsylvania in recent years, what was the cause of the leaf-spot which is said to have existed in Lancaster county long before wildfire is presumed to have been introduced? The older tobacco growers state that "rust" was known during their youth; as far as they knew it had always occurred at times in this locality. This "rust" was the type associated with wet weather and maturity. A season is recalled, in the early eighteen-nineties, when damage was so severe that some crops were scarcely worth cutting. It is impossible to ascertain at this time whether this damage was physiological or parasitic; but recent experimental evidence suggests that the leaf-spot occurring in earlier years was caused by *Bacterium tabacum*.

The reason that the parasite was first noted in North Carolina in 1917 (20) and a brief time later in Connecticut (10) may well be that the presence of wildfire in these regions was a new or unusual phenomenon and hence attracted attention. It is noteworthy that the disease was first brought to attention in a district from which it has now apparently disappeared and not where it has become a recurrent problem. Fromme and Wingard (12) have presented evidence which indicates that *Bacterium angulatum* was the probable cause of damage to tobacco in Virginia during colonial times. It is not at all improbable that wildfire has had a somewhat parallel occurrence in Pennsylvania and Maryland.

In Lancaster county, wildfire has occurred in seed beds every year since 1921, when the disease first received the attention of the pathologists of the Pennsylvania Agricultural Experiment Station, although damage has not always been caused in the field. A survey made in 1921 by W. A. Kuntz[3] showed that the disease was generally distributed in the county, with losses ranging from a trace to 60 per cent. The notes of Kuntz imply that the disease occurred on certain farms in 1920. The prevalence found at this early period would indicate that the wildfire organism had been present several years. There is the usual assumption, however, that the disease had been introduced during the same general period that it was being reported in other tobacco regions, from 1918 to 1921.

Results of Previous Investigations

Earlier investigations of wildfire in Pennsylvania (4) indicated that the increasing prevalence of the disease probably was associated wholly with such factors as (a) permanent seed-bed locations which continue to harbor contamination after once becoming infested; (b) the frequent proximity of seed beds to barns in which infected crops are stored; (c) the difficulty of or neglect in performing effectively all the sanitary measures required to prevent seedling infection; (d) the sale or exchange of infected seedlings; (e) the small size of many Lancaster county farms, which makes it impossible to isolate plantings far from tobacco barns or neighboring infected fields; (f) the rolling character of the land, which favors surface washing and the transportation of dis-

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eased tobacco debris from adjoining fields; and (g) the necessity of a high degree of community cooperation for the greatest success in combating the disease. All these factors are unquestionably obstacles to the satisfactory control of wildfire.

As the investigation of the disease and the promotion of control among farmers progressed, it became evident that these obstacles would make the prevention of seed-bed infections by sanitary measures difficult at best, and often wholly ineffectual with inexperienced workmen. Sterilization of the seed-bed soil by steam was already practiced generally. Further recommendations included the disinfection of seed, old bed frames, cloth or sash covers,

FIG. 2. WILDFIRE SPOTS (AS RIGHT) THAT RESEMBLE, IN OUTLINE, "ANGULAR LEAF SPOT," *BACTERIUM ANGULATUM*

These occur on mature tobacco during wet weather. They are dark brown to black. At the left is a typical wildfire spot of earlier development.

and other necessary equipment. Moving the seed beds to locations that are free of contamination and at a distance from tobacco barns was urged. Safe places were not always available, however, and many farmers were not disposed to move far enough from contaminated buildings, because of the lack of shelter and inconvenience in watering. Hence, the protection that might be provided by some kind of spray or chemical treatment of the tobacco seedlings appeared essential, in order to counteract the danger that some feature of sanitation be overlooked or prove inadequate.

Seed-bed Experiments. Since investigators then were not in full agreement concerning the value of bordeaux mixture or copper-lime dust in seed-

bed treatment, (2, 10, 14), experiments with them were undertaken, particularly with respect to the time and the manner of application. Earlier application of the first treatment appeared important, since diseased tobacco refuse might be present about seed beds at the time the seed was sown. Furthermore, the frequent use of mulches, such as straw or hog bristles, to promote germination had tended to delay spraying or dusting by growers. The experiments indicated that the application of bordeaux mixture as early as seedtime was feasible. As a result, field plots entirely free from the disease were obtained experimentally in spite of heavy contamination in the form of cured infected tobacco leaves broken up and scattered in the seed beds (Table 3). This result, however, was obtained consistently only in a locality where wildfire was not widely prevalent.

In localities where the disease is general, sanitary measures, together with efficient spraying of seed beds with Bordeaux mixture at seedtime, or when the first true leaves appeared, with at least weekly applications until transplanting, have not always ensured satisfactory wildfire control under actual farm practice. The fact that only a minority of the tobacco growers in heavily infected localities have thoroughly performed all necessary combative measures, together with current weather factors, have contributed to the lack of satisfactory control.

Field Demonstrations. In 1934, 17 farm demonstrations of the most effective seed-bed control methods were conducted. In addition to sanitary precautions, the seed beds were sprayed with bordeaux mixture. The seed beds themselves remained free of wildfire, according to inspections made by F. S. Bucher, County Agricultural Agent. Of the fields set from these beds, however, only one escaped wildfire infection, 4 had but a slight amount, and 12 exhibited varying degrees of damage, in some cases severe. One severely infected field was on land that had grown a diseased crop in 1933. In several cases, the edges of infected fields were within 50 feet of tobacco barns which had stored diseased crops the previous year. Other cases could be explained only by the presence of contamination along borders, in adjoining fields or in the field itself, unless it be assumed that seed-bed infection had escaped notice. The data upon the over-wintering of wildfire presented in this bulletin make it appear probable that these demonstrations would have been more successful had they not followed the unusually wide-spread wildfire devastation of 1933. Rainfall during August of that year totaled 13.94 inches at Lancaster. The extensive amount of flowing surface water transported infested debris and many fields and borders where tobacco was not grown appear to have become contaminated.

Over-wintering of Wildfire in the Field

In Other States. Clinton and McCormick (10) report but a single experiment in Connecticut which gives any indication that the wildfire organism over-winters in the field. Anderson and Chapman (3) record six cases in Massachusetts, in 1922, in which field infection apparently came from sources other than the seed bed. Anderson (1) found that the parasite over-winters in the Connecticut Valley on old stalks, suckers, and leaves left in the field under conditions in which decay does not progress readily, but that it does not survive when the tobacco remnants are incorporated with the soil. He recom-

mended that all stubble and leaves be plowed under as soon as the tobacco is removed, to aid the decay of material harboring the disease. Johnson and Murvin (16) report experiments in Wisconsin which shows that the wildfire organism can live in dry tobacco leaves mixed with air-dry soil long enough to carry it over to the crop of the next year; but that the bacteria live scarcely a month when dry leaves are mixed with moist soil, as in the field. These workers conclude that there is no danger in growing tobacco again on land from which a wildfire-infected crop has been harvested the year previous, provided all refuse is plowed under.

Thomas (17), on the other hand, reports an experiment in New York in which old tobacco roots, stems, and leaves were gathered in April from a badly infected field of the previous year and then buried a few inches in the soil in a locality where tobacco had not been grown within a radius of 20 miles. Healthy tobacco plants were set out on this soil in June. Because of a dry season, there was no observable disease until September, when a few spots of wildfire developed. A considerable increase of infection followed during October.

In Lancaster County. Observations on the sources of wildfire infection in tobacco fields in Lancaster county revealed frequent instances in which it was questionable whether primary infections originated in the seed beds. Other investigators (1, 16) have reported seed-bed origin of wildfire in practically all cases, in their respective tobacco sections. A survey of 79 farms in Lancaster county, Pennsylvania in 1931 (4) showed 16 tobacco fields with more or less wildfire, although the seed beds had been inspected before and during transplanting to be certain that they had no disease.

These observations first led to a search for wild plants which might be hosts of *Bacterium tabacum.* No proof was obtained, however, that the disease on the tobacco came from this source. Further study of many diseased fields, not due to seed-bed infection, indicated that the remnants of tobacco from the previous crop deposited along borders, or on fields adjoining growing tobacco, or plowed under in the present fields, might be important sources of the disease. In Lancaster county, fields that have grown tobacco are commonly sown to winter wheat without plowing. Discing, the usual method of preparing the soil for wheat, does not thoroughly cover the tobacco butts and scattered leaves. A considerable number of fields are left untouched until the following spring. Suckers often spring up in the fall and become infected with wildfire. Flowing surface water often transports tobacco waste into plantings of growing tobacco. The frequent proximity of tobacco barns or other sources of contaminated waste have been mentioned; in such cases, wind may be the transporting agent.

Experiments in Over-wintering

In order to determine how long the wildfire bacteria remain viable in or on tobacco tissues subjected to varying conditions, the materials were distributed upon small beds of healthy seedlings during the time most favorable for wildfire development. In Pennsylvania, this time is from the middle of May until July, in the case of out-of-door seed beds, which were used in most instances. Conditions for infection are again quite favorable from late August until October, but suitable seedlings for use during this period are obtained with difficulty.

Viable wildfire bacteria were found in cured tobacco two years after its harvest. Tests during the third year, however, were all negative. Butts, stalks, and scattered leaves left to weather upon the field from cutting time until the following summer gave few infections as compared with material stored in barns for the same period. Mature plants left standing to be killed by frost were more likely to harbor the disease than plants lying on the ground, in tests made the following June. Infections were obtained in 2 out of 6 tests from the woody parts of butts and roots which had been turned into the soil by plowing just after the tobacco was cut, but which had been brought to the surface by the harrow during the preparation of the soil the following spring. In each of these tests, approximately a peck of the butts or roots were gathered from a field where wildfire had been severe.

Negative results were obtained from tests of soil in which infected tobacco had decayed to the point of disintegration during the period from fall until the following June; or during 60-day periods when temperatures and moisture conditions were made favorable for rapid decay by placing the soil and tobacco material in jars indoors. The 12 soil tests were made by filling greenhouse flats with 20 pounds of soil and growing tobacco seedlings. Woody or undecayed portions of the tobacco plant were absent in these tests.

Field Tests in 1932. Experiments with wildfire over-wintering were begun at State College in 1932. Since tobacco had not been grown there for a number of years, and is not a commercial crop near State College, conditions are favorable for a test of whether infected tobacco waste, such as is common about fields in Lancaster county, is a source of wildfire infection when incorporated with the soil. Furthermore, the soil is the same type as that in Lancaster county —Hagerstown loam over-lying limestone. The soil reaction also is similar, tending to be alkaline.

A quantity of stalks from infected plants that had lain on open ground over winter were plowed into a plot in April. Disease-free tobacco seedlings were set on this plot on June 10. The plot was on comparatively low ground that tended to become flooded for a brief time after any considerable rainfall and to remain wet for several days. The first heavy rain after transplanting occurred July 1. An examination made a week later showed 18 of the 159 plants on the plot to be infected with *Bacterium tabacum* (Table 1). This result was in agreement with that reported by Thomas (17). The weather at State College was favorable to wildfire in 1932, and several plots well separated from each other became uniformly infested.

Field Tests in 1933 and 1934. The tobacco on the infested plots was cut down late in September and the land plowed. The plants were laid in the furrows and covered. This placed an unusual amount of infected material in the soil. Care was taken to cover all tobacco remnants and other vegetation, such as weeds, along the borders where contamination could have occurred. In 1933 and again in 1934, the infested plots were set with disease-free plants. In preparing the ground for planting, the soil was disced and harrowed early in June, but in 1933 the spring was so wet that it was necessary to replow some of the plots to destroy weeds. At transplanting time, the only discernible remnants of the previous tobacco crop were woody fragments of roots and main stems.

TABLE 1. EXPERIMENTS SHOWING THE OVER-WINTERING OF *BACTERIUM TABACUM* IN THE FIELD FOLLOWING THE GROWTH OF AN INFECTED TOBACCO CROP AS INDICATED BY DISEASE-FREE SEEDLINGS TRANSPLANTED THE NEXT YEAR

Experiment number and year	Manner of field infestation and experimental conditions	Number of plants on plot	Date of first infections	Number of plants deriving infection from field	Crop loss at cutting time
No. 1–1932	Infected tobacco stalks plowed into soil in April. Soil very wet after rains.	159	July 8	18	49%
No. 2–1932	Check with no infestation	160	July 8	0	0
No. 1–1933	Wildfire previous year fall plowed	50	July 7	1	3
No. 2–1933	Wildfire previous year fall plowed	50	Sept. 30	3	0
No. 3–1933	Wildfire previous year, fall plowed and replowed following June	50	Aug. 5	1	10
No. 4–1933	As above	100	July 7	4	22
No. 5–1933	As above	300	Oct. 3	2	0
No. 6–1933	As above	300	Aug. 28	3	0
No. 7–1933	As above	250	Sept. 2	2	1
No. 8–1933	Check with no infestation	100	Oct. 3	0	0
No. 1–1934	Wildfire the previous year, fall plowed	800	July 9	5	8
No. 2–1934	As above	60	Sept. 20	1	0
No. 3–1934	As above	50	Aug. 12	2	20
No. 4–1934	Check with no infestation	50	Oct. 1	0	0

The results of these tests are given in Table 1. The degree of over-wintering is indicated by the number of primary infections that appear to have been derived from the immediate environment rather than from adjacent diseased tobacco plants. During the years 1932 to 1934, eleven plots were used to test the over-wintering of the wildfire organism in the field. In all of them some disease appeared. The relatively low proportion of primary infections and the late development of some of these suggest the possibility of occasional seed-bed infections on the one hand, or of secondary dissemination from other infected plots, on the other. However, the check plots and likewise the seed beds on which a few plants were left to mature remained altogether free of disease to the close of the seasons 1933 and 1934. Moreover, the plots reported in Table 3, which were set with seedlings from beds treated with bordeaux mixture, copper-lime dust, and calomel during these same years, may be considered checks upon extraneous infections. There were 10 such plots. All of them remained free of disease.

Only one experiment has been completed to test whether *Bacterium tabacum* can live for a period of two years in cultivated fields when tobacco is not grown. Fifty tobacco plants were grown to maturity on soil which had been contaminated by plowing down an infected tobacco crop two years previous.

There was no reappearance of wildfire. Observations on infected fields in Lancaster county, where wildfire has not been traced to the seed bed, have shown probable contamination one year previous.

Shading in Relation to Wildfire Control

It often has been observed that wildfire is much less severe in the shelter of buildings and trees and that damage is usually greatest in exposed places, al-

FIG. 3. TOBACCO PLANTS GROWN UNDER SHADE
Wildfire infected seedlings may develop essentially disease-free tobacco beneath shade cloth. Shading tends to prevent the spread of the disease by the decrease in rain splashing.

though infestation may be equal. In 1928, 1929, and 1930, tents to accommodate 200 plants were built within plantings of tobacco in Lancaster County; in 1932 and 1933, tents to accommodate 25 plants were built at State College. The cloth was that commonly used for shading tobacco in New England and elsewhere. A few tents were made with the finer mesh cloth used for seed-bed covers.

There was a decided reduction in the amount of wildfire infection beneath these comparatively small tents. Although only infected seedlings were transplanted beneath the tents in two instances, the reduction of the disease was almost to the point where there was no further spread. At harvest, the crop appeared practically clean, since most of the leaves spotted at transplanting had

withered and shattered. In contrast, plants growing outside the tents were severely infected; the spotting extended to the uppermost leaves. Similar results were obtained under cloth cages constructed for the study of insect dissemination of wildfire.

No explanation can be offered that will cover all possible features of this reduced or inhibited infection. Reduced light, with the resulting modification of leaf structure and leaf composition, may have some effect on resistance. The leaf tissues become less watersoaked during rainfall. The cloth breaks up the raindrops, resulting in a relatively gentle movement of water downward and off the leaf blades. There is little of the upward splashing which enables the bacteria to reach the higher leaves. There is slight movement and almost no inverting of leaf blades, hence there is less injury of the leaves which offers easy entrance to the parasites. There is less exposure of the lower leaf surface to wind-driven raindrops. The water-soaking of the leaf tissues, which Clayton (9) has discussed, is far less likely to occur; in fact, it is exceedingly difficult to bring about the water-soaked effect unless the water is directed against the lower surface of the leaf. The greater number of stomata in the lower epidermis—about 2½ times more than on the upper side of the leaf—and the position of the spongy parenchyma doubtless account for the greater tendency to water-soaking on the under side.

In order to test the effect of a source of wildfire bacteria from above the plant, two small bunches of infected tobacco leaves were suspended above two growing tobacco plants within a shade tent 12 feet square, in 1933. Although there were a number of periods of rain when wildfire spread extensively in the open, spots of infection beneath the suspended leaves were limited to 9 and 3 on the respective plants. These infections were directly in the line of water dripping from the suspended leaves. Apparently there were no infections as a result of splashing, which covered a circle with a radius extending several feet beyond the line of dripping. The fact that the lower leaf surfaces were not exposed may have had an important influence on this result. At least, it appears that factors other than the dissemination of the bacteria and the dampness requisite for infection influence the amount of wildfire on shaded plants (Fig. 3).

Wild Plants as Hosts of Wildfire

Johnson, Slagg, and Murvin (15) showed that *Bacterium tabacum* can produce lesions characteristic of wildfire upon a wide variety of plants distributed among several distinct botanical groups. What was considered infection was obtained by them under very favorable environmental conditions, such as may be provided by keeping the tobacco under moist chambers in the greenhouse. Wound inoculation was the rule but was not necessary with some plants. Johnson and Murvin (16) found that the yellow halo surrounding the wildfire infection is caused by a soluble toxin, that this toxin can be separated from a culture of *Bacterium tabacum* by filtration and that it produces an effect like wildfire when inoculated into tobacco leaves. Clayton (8) extended the inoculation tests with the toxin filtrate to a large variety of plants with comparable results, and he advanced the view that *Bacterium tabacum* is truly parasitic only upon species of *Nicotiana*. On the other apparent hosts, he

states that the toxin alone is responsible for the characteristic halo and may kill some leaf cells; and that the parasite exhibits only slight signs of multiplication and invasion of the respective leaf tissues.

The rarity with which wildfire symptoms are found in nature on various species of plants associated with badly infected tobacco indicates a limited host range. The importance, however, of determining the ways that *Bacterium tabacum* may over-winter, or may sustain itself, possibly for several years, in the absence of growing tobacco, has made a search for wild or other cultivated hosts a prominent feature of investigation. This seemed especially important in Lancaster county, where there have been repeated outbreaks of wildfire.

Wildfire on the Ground Cherry. The numerous species examined during wildfire epidemics and in locations suspected of being primary sources of disease in tobacco fields need not be mentioned. Thus far only one species, *Physalis virginiana,* has been found that has exhibited lesions characteristic of wildfire. This is one of the wild ground cherries and a common weed of roadside and field. The lesions upon this weed were first noted during the uncommonly severe wildfire epidemic of 1933. Specimens were found near diseased tobacco in different parts of the county in 1933, but were much less common in 1934. The apparent infections on this ground cherry centered mostly on injuries or small holes in the leaves made by the feeding of tobacco and potato flea beetles (Fig. 4). Microscopic examination revealed numerous bacteria in the small areas of dead tissue at the center of the spots, and there was no difficulty in obtaining cultures that gave typical wildfire infection upon tobacco. The isolations were all made within 2 or 3 weeks following the probable time that the spots developed in nature. In one series of platings, colonies of *Bacterium tabacum* were predominant, but in others saprophytic forms were predominant, with few or no colonies of the wildfire organism. The predominance of saprophytes occurred in the older collections of material, but the same experience may occur in isolations from tobacco. Altogether, there was considerable evidence that the parasite had multiplied within the leaf tissues of the ground cherry.

In 1934, seedlings of *Physalis virginiana* were grown and set out among tobacco plants infected with wildfire. Following each rain, observations were made on the spread of infection on both species of plants. Wildfire spots on the tobacco increased whenever conditions were favorable, but none was found upon the ground cherry until late in the season, and then the lesions were confined to injuries made by flea beetles. Meanwhile, inoculations were made from pure cultures of *Bacterium tabacum.* It was found that wounding was necessary to assure the development of lesions on the ground cherry in the garden during damp weather and without a bell jar covering. Further search was made in Lancaster county where the ground cherry was growing amid old tobacco refuse or where there had been infected tobacco the previous year. No signs of wildfire lesions were observed, although the holes made by the flea beetles were numerous in all cases. Experiments have shown that in such situations tobacco becomes infected (Table 1).

FIG. 4. WILDFIRE ON THE GROUND CHERRY *(PHYSALIS VIRGINIANA)*
Left, a branch of the wild ground cherry, showing a leaf with spots from which the wildfire organism was isolated. Right, an experimentally infected leaf showing the characteristic wildfire halos. All the leaves show numerous holes made by the feeding of potato or tobacco flea beetles.

The results obtained with *Bacterium tabacum* upon *Physalis virginiana* seem to correspond in most respects to those reported by Clayton (8) for a series of garden plants not belonging to the genus *Nicotiana.* The evidence is meager that the wild ground cherry performs the role of a carrier of wildfire. The bacteria may become lodged in wounds on various plants and may multiply to a limited extent under particularly favorable conditions, but this would have to occur in the absence of tobacco to be significant.

Flea Beetles as Carriers of Wildfire

The abundance of tobacco and potato flea beetles on tobacco, and the frequent wildfire infection about the small holes which they make in the leaves, leads to the rather plausible supposition that these insects transfer the organism. However, experimental evidence that these insects are actual agents in the transfer of the disease has not been obtained. At periods when the occurrence of the flea beetles and wildfire have coincided, the insects have been captured, allowed to feed on infected tobacco leaves, and then released upon healthy tobacco plants within muslin or glass cages. During the past five years, 18 such experiments have been made, each involving not less than 50 insects, and often many more.

The flea beetles were confined in wide-mouthed flasks or bottles of 1000 cc. capacity with a piece of tobacco muslin stretched over the opening. The in-

fected tobacco leaves placed within these containers were sprinkled slightly with an atomizer, or picked with dew upon them, to keep them fresh as long as possible and to favor the exudation of bacteria. One difficulty is that the insects do not behave normally in confinement; they spend most of the time seeking to escape. In only a few of the trials was there any considerable amount of feeding upon the detached leaves. With dampness present, the chance that bacteria would adhere to the bodies of the insects seemed greater than in nature, since flea beetles are active chiefly during clear, dry weather. After release upon the plants within the cages, the insects seek the light and oftener than not they fly to the surface of the muslin or glass. A considerable proportion of them usually escaped in some manner. In the 18 experiments, however, approximately 500 points of feeding were observed. In only three instances did lesions resembling wildfire result. In these, very few bacteria were observed and these could not be reclaimed.

In the various seed beds maintained for experimental purposes, a few plants usually were left to grow to maturity. A portion of these beds was kept disease-free, at least early in the season. The individual beds were not separated beyond flying distance for the flea beetles, yet no decisive evidence that flea beetles carried infection across intervening spaces was obtained. When transfer did occur, it was traceable to other agents, usually rain storms. The infections mentioned as occurring around the holes which the flea beetles make in feeding are practically always close enough to older wildfire lesions, or infected soil, to make it more probable that transfer was from these sources, through the agency of splashing rain. The habits of flea beetles tend to make it unlikely that they would transport wildfire bacteria, or that infection would result if they were transported. These insects are repelled by shade, and are active or feed chiefly during clear, dry weather when bacteria are not exuded from lesions and when tobacco leaves are less susceptible to infection.

Experiments With Sprays or Dusts in Seed Beds

In order to test the relative efficiency of chemical compounds applied to seed beds as sprays, dusts, or drenches for the prevention of wildfire, plots in the beds were contaminated with cured, infected tobacco leaves from the previous harvest. The leaves were broken into small fragments and a quantity scattered over the surface of the prepared beds. This method of ensuring contamination never failed to result in wildfire, in the absence of preventive treatments. It was selected because of its convenience and because it corresponded to conditions met on farms. The chief difference in infestation between the experimental plots and farm seed beds was probably only in degree. The contamination was made severe purposely in order to reveal the most efficient preventive.

The experimental beds were either 27 or 36 square feet in area and were enclosed with a frame of boards. The cross dimension was six feet so that standard sash or tobacco muslin could be used as cover. The soil was sterilized with steam, usually for 30 minutes, and mostly for the purpose of destroying weeds. For the sake of uniformity and to provide check plots, muslin, sash, and board frames that had been used in previous years were sterilized. The beds were sown with disinfected seed at the customary time, early in April, since it was necessary to take advantage of the optimum period of wildfire

development during May and June. The time when the plots were contaminated varied; but it always was subsequent to seed-bed preparation and prior to control treatments. When there was danger of disease spreading from one plot to another, an intervening aisle of 12 to 15 feet was maintained.

Earliness of Application. The principle of disease control adhered to in the experiments with preventive sprays or dusts here reported was to approach as nearly as possible to absolute prevention without serious harm to the tobacco seedlings. Observations by Valleau (18) revealed the frequency with which seedling leaves that touch the soil exhibit the first lesions. Infected tobacco refuse, if present, is commonly deposited on or in the soil, and the bacteria issuing from such material presumably become suspended in soil water and then come in contact with the growing seedlings. A timely application of a bactericide to the soil should destroy these bacteria before they are able to infect; and the dead tissues of the old tobacco may be penetrated by the bactericide and the bacteria killed.

Spraying with bordeaux mixture is largely futile after only a very few wildfire lesions have developed on seedlings (4). Delaying the first application until the leaves become the size of a dime allows a considerable period in which the seedlings have no protection, unless sanitary measures have been perfect. It may be questioned whether the lower temperatures of early spring should be depended upon to prevent infection until the seedling leaves reach the size of a dime, or even less, when it is probable that contamination is present. Early periods of warm weather are not unusual, and many beds are in protected places. The spraying of seed beds by farmers in Lancaster county resulted in numerous failures until the time of the first application was advanced to the seed-leaf stage.

Injury to Seedlings. Farmers have objected to beginning the application of bordeaux mixture early, for fear of injuring the tender seedlings. Experiments were undertaken to determine whether a satisfactory stand of tobacco seedlings could be grown when bordeaux mixture and other fungicides were applied to the soil at seedtime. The results with bordeaux mixture and copper-lime dust (Table 2) were uniformly favorable. Bordeaux mixture in 1-1-50 and 2-2-50 strength was applied at the rate of a quart to a square yard of bed surface. Enough copper-lime was applied to give an amount of copper equal to that applied in the bordeaux mixture. No loss of stand or significant injury to growth was apparent when the seed was sown dry. Numerous tests by farmers in Lancaster county were conducted afterward in which a 4-4-50 bordeaux spray was applied to the soil of beds at seedtime without injury to the plants. An examination of seedling root tips under a miscroscope has revealed some injury from seedtime treatment, but secondary roots are formed, and the injury is slight.

The sprouting of tobacco seed in bulk in order to hasten germination is of doubtful value, but it is a rather common practice. Bordeaux mixture treatment of bulk-sprouted seed, after sowing, may cause a considerable reduction of stand. This amounted to 23.7 per cent and 31.4 per cent respectively in experiments 7 and 8, as compared with experiment 9 which, received no treatment (Table 2). The 65 per cent stand obtained with bulk sprouting and

no treatment was used as a base in computing the reduction of stand. Such a reduction need not make the treatment impracticable, since more seed could be sown. However, a great proportion of the Lancaster county seed beds are too

TABLE 2. THE EFFECT OF BORDEAUX MIXTURE ON THE GERMINATION OF TOBACCO SEED AND THE STAND OF SEEDLINGS IN GREENHOUSE FLATS
Objectionable Injury Is Not Evident

Experiment	Number of seeds	Condition of seeds	Treatment	Per cent germinated and rooted	Per cent germinated but failing to root	Final growth and stand
No. 1	1250*	Dry	1-1-50 bordeaux mixture on soil	73.6	Negligible	Good
No. 2	1250	Dry	4-4-50 bordeaux mixture on seed	75.3	Negligible	------------------
No. 3	1250	Dry	Copper-lime dust on soil	73.1	Negligible	Good
No. 4	1250	Dry	Silver nitrate sterilization of seed	68.8	Negligible	Good
No. 5	1250	Dry	No treatment	71	Negligible	Good
No. 6	1250	Dry	No treatment	68.5	Negligible	Good
No. 7	1000	Bulk sprouting 48 hrs.	2-2-50 bordeaux mixture on soil	49.6	23	Satisfactory
No. 8	2500	Bulk sprouting 65 hrs.	As above	44.5	26	Fair
No. 9	2500	As above	No treatment	65	7.2	Good
No. 10†	13,250	Dry	2-2-50 bordeaux mixture on soil	No record	No record	Good
No. 11†	13,250	Bulk sprouting 36 hrs.	As above	No record	No record	Somewhat thin stand but good growth

* A decigram of tobacco seed weighed on a fine balance was found to average 1250 seeds and the number of seeds was determined by weighing.
†Experiments No. 10 and No. 11 were conducted in an out-of-door seed bed.

thickly sown to give the best type of plants. The stand obtained in experiment 11, Table 2, in which the seed was bulk-sprouted 36 hours and sown at the standard rate, was sufficiently thick in spite of the application of bordeaux mixture at seeding.

Bordeaux Mixture and Copper-lime Dust. Anderson (2) and Clinton and McCormick (10) found bordeaux mixture and copper-lime dust to be effective in protecting tobacco seed beds in Connecticut against wildfire infection, and these materials are commonly used in the Connecticut Valley. Johnson and Murvin (16) found little or no value in these treatments in Wisconsin; they present data to show that infections occur in spite of applications of sprays or dust. In their experiments, the tobacco seedlings were covered with pure culture suspensions of *Bacterium tabacum,* with an atomizer, before or after applying the fungicides. These conditions correspond in large measure to those existing in seed beds after some wildfire lesions have developed on the seedlings; effective control is no longer possible when such infection has occurred. Anderson and Chapman (3) did not secure complete control under such conditions in Massachusetts; their early experiments are comparable to those by Johnson and Murvin.

The situation is different, however, when the fungicides are applied to the seed-bed soil, or early enough to be entirely preventive, thus enabling the disease bacteria to be destroyed first hand as they issue from their dormant

state in old host material. When the treatments are made at seedtime or at the seed-leaf state, somewhat prior to the usual appearance of wildfire, complete control has been secured. During a period of three years, 1932 to 1934 inclusive, contaminated seed beds in Pennsylvania have been kept entirely free of wildfire (Table 3). Random samples of seedlings taken from each experimental bed, as an additional test for freedom from infection, gave field plots that developed no wildfire whatever throughout the season. Each of the experimental beds was estimated to contain 10,000 seedlings and probably a greater number in most cases. These experiments had the advantage of a considerable area of land known to have no infestation by wildfire, so that each field plot could be isolated. Recently Valleau (19) has reported that 2-3-50 bordeaux mixture applied by sprinkling at the rate of a quart to the square yard when the seedlings showed the first true leaves gave protection against angular leaf spot for the remainder of the seed-bed period.

The necessity of commencing treatments at seedtime is not demonstrated decisively in Table 3, in which applications at seedtime, at the seed-leaf stage, and when leaves are the size of a dime are compared. The results with bordeaux mixture appear equally effective whether the material is applied at the seed-leaf stage or at seedtime, although contamination was made at seedtime in both cases. However, experiment 4, in 1932, proved ineffective when the bed was contaminated at seedtime and the first application was delayed until the leaves reached the size of a dime. Experiment 6 with copper lime dust, and experiment 8 with calomel drench proved ineffective when the delay was only to the seed-leaf stage.

In Lancaster county, there has been an advantage in applying bordeaux mixture to beds at seedtime when mulches, such as straw or hog bristles, are spread upon the beds to aid germination. Not only is there a tendency to leave these mulches in place much beyond the seed-leaf stage, but these materials may be an actual source of contamination. In the case of permanent beds, the disinfection of frames, aisles, and approaches is a necessary sanitation measure. Drenching with bordeaux mixture is inexpensive and effective. It is convenient to extend this treatment to the beds, merely using a weaker mixture, such as 1-1-50, at the rate of a quart to the square yard.

Calomel. Although the mercury compounds used as fungicides are more or less injurious to tobacco seedlings, in most cases calomel has been only slightly toxic when used on the tobacco soils of Pennsylvania. It has been used without serious ill effects by certain farmers in Lancaster county who became acquainted with its value for preventing wildfire by observation of the experimental seed-beds. It seemed to them to possess a moderate advantage in that it could be used, in an emergency, without any special equipment. It is possible that soil condition, such as good tilth, a liberal organic matter content, good water-holding capacity and an alkaline reaction, have tended to suppress the toxic action of calomel.

In common with other mercury compounds, calomel produces an abnormal root system in tobacco. There is a rather slender main root for a considerable depth before any secondary roots are formed (Fig. 5). Apparently the primary root must reach a soil depth where it can escape the toxic action of the chemical before growth proceeds normally and branch roots are formed. Occasionally, general stunting is observed for a while in a bed of calomel-

treated seedlings, after which a few plants at a time begin to exhibit more rapid and normal growth. The peculiar root system makes these injured plants hard to pull; often the secondary roots break off, leaving only a comparatively short primary root, which is unsuited to transplanting. Unless moisture conditions are very favorable, an unduly large proportion of the plants have to be replaced in the field. Calomel-treated plants are likely to be slow in starting to grow after transplanting; a delay in maturity of two weeks is not uncommon.

FIG. 5. INJURY TO TOBACCO PLANTS IN THE SEED BED BY CALOMEL
Left, the root system of a normal tobacco plant. Right, the abnormal root system which calomel or organic mercury compounds may produce. The development of secondary roots near the soil surface is largely prevented.

Calomel can be applied only after the seedlings have become well rooted. In the experiments recorded in Table 3, the seedlings were developing the first true leaves when the treatment was given. In order that the calomel tests might be comparable with the tests with bordeaux mixture, the beds were not contaminated until the first true leaves appeared, in a part of the trials. Calomel was not as effective as bordeaux mixture unless combined with a material that would make it adhere to the leaves, as skimmilk powder. This was mixed with the calomel dry, in the proportion of 3 to 1 by weight. The mixed materials then were stirred into water at the rate of two teaspoonfuls to the gallon. The milk powder aided in bringing the calomel into suspension, but

did not prevent it from settling to an appreciable degree. Frequent agitation was required to maintain the material in suspension while the mixture was sprayed upon the tobacco plants.

Experiment 9, in 1932, experiments 5 and 6, in 1933, and experiment 4, in 1934 (Table 3) show that the calomel and milk powder spray entirely prevented seed-bed infection and resulted in field plots that remained disease-free throughout the season. However, the danger of stunting the plants and

TABLE 3. COMPARATIVE TESTS OF BORDEAUX MIXTURE, COPPER-LIME DUST, AND CALOMEL-MILK-POWDER SPRAY IN PREVENTING WILDFIRE INFECTION IN TOBACCO SEED BEDS WITH VARIATIONS IN THE TIME OF FIRST APPLICATION

The beds were contaminated at seedtime with cured wildfire-infected tobacco except where otherwise stated

Experiment and Yr.	Treatment and number of applications	Time, or stage of growth, of seedlings at first application	Degree of infection observable in seed bed	Degree of infection of a random sample of plants transplanted to an uninfected plot in the field
No. 2–1932	2-2-50 bordeaux mixture spray 6 applications	At seedtime	None	No infections of seed-bed origin *
No. 2–1932	2-2-50 bordeaux mixture drench 2 applications, 4-4-50 spray 4 applications	At seedtime	None	None
No. 3–1932	4-4-50 bordeaux mixture spray 6 applications	At the seed-leaf stage	None	No infections of seed-bed origin*
No. 4–1932	4-4-50 bordeaux mixture spray 4 applications	Seedling leaves the size of a dime	None	Two plants among 150 with infections of seed-bed origin
No. 5–1932	Copper-lime dust 15% mono-hydrated copper sulphate, 8 applications	At seedtime	None	Result doubtful *
No. 6–1932	Copper-lime dust as above 6 applications	At the seed-leaf stage	None	One plant with infection of seed-bed origin among 145
No. 7–1932	Calomel a gram to a sq. yd. as a drench 6 applications	At seedtime	None, but plants were stunted	None
No. 8–1932	Calomel as above 6 applications	At the seed-leaf stage	13%	----------
No. 9–1932	Calomel-milk-powder spray 5 applications	At seed-leaf stage. contamination at this same time	None	No infections all season, plants late in maturing
No. 10–	No treatment	----------	64%	Serious infection on all of 150 plants
No. 1–1933	Bordeaux mixture 2-2-50 drench first applications, 4-4-50 spray 4 applications	At seedtime	None	No infections all season, 100 plants
No. 2–1933	Bordeaux mixture 4-4-50 spray 5 applications	At seed-leaf stage	None	25 plants left on seed bed without infection all season
No. 3–1933	Copper-lime dust as Exp. 5, 1932, 6 applications	At seedtime	None	No infections all season, 100 plants
No. 4–1933	Copper-lime dust as Exp. 5, 1932, 5 applications	At seed-leaf stage	None	25 plants left on seed bed without infection all season

TABLE 3 (Continued)

Experiment and Yr.	Treatment and number of applications	Time, or stage of growth, of seedlings at first application	Degree of infection observable in seed bed	Degree of infection of a random sample of plants transplanted to an uninfected plot in the field
No. 5–1933	Calomel and milk powder spray 5 applications	At seed-leaf stage	None	No infections all season, 100 plants. Crop late maturing
No. 6–1933	Calomel and milk powder spray 3 applications	At the seed-leaf stage. Contaminated in 1932	None	No infections all season, 100 plants. Crop late maturing
No. 7–1933	No treatment	----------	43%	Moderate infection on all plants
No. 1–1934	Bordeaux mixture 1–1–50 drench first application, 4–4–50 spray 4 applications	At seedtime	None	No infections all season, 100 plants
No. 2–1934	Bordeaux mixture 4–4–50 spray 4 applications	At seed-leaf stage	None	25 plants left on seed bed without infection all season
No. 3–1934	Copper-lime dust as Exp. 5, 1932, 5 applications	At seedtime	None	No infections all season, 100 plants
No. 4–1934	Calomel and milk powder spray 4 applications	At the seed-leaf stage. Contamination at the same time	None	No infections all season, 100 plants
No. 5–1934	No treatment	----------	Moderate infection	Moderate infection of all plants

*In 1932, the field plots were only one rod apart and a rainstorm occurring July 15 carried the disease across the intervening space in a few cases.

the delay in maturing the crop will tend to make the use of calomel unsatisfactory in spite of its effectiveness in wildfire control, especially since bordeaux mixture meets all the requirements of an efficient wildfire preventive in seed beds, and does not have the disadvantages of calomel.

Miscellaneous Chemicals. The results of tests of other chemicals, including mercury compounds, are recorded in Table 4. None of these was particularly promising and some were injurious. Milk of lime showed an unexpected capacity to suppress infection. Johnson and Murvin (16) obtained a less pronounced reduction of infection with limate and calcium caseinate but regarded the action as mechanical.

Discussion of the Control Problem

Both experimental evidence and the experience of farmers show that a program for the control of tobacco wildfire in Pennsylvania that is based solely on the use of disease-free seedlings may not be wholly satisfactory when natural conditions favor the over-wintering of the disease in the field, or when cultural practices render the contamination of the seed beds probable. Table 1 shows that *Bacterium tabacum* survives rather commonly in infested fields for a full year, and perhaps longer. This survival creates the possibility of heavy damage, if the primary infection of transplanted tobacco occurs early

TABLE 4. TESTS OF MISCELLANEOUS CHEMICALS AS PREVENTIVES OF WILDFIRE IN TOBACCO SEED BEDS

The beds were contaminated with cured infected tobacco leaf material just prior to the first treatment

Treatment	Stage of growth of seedlings at first application	Number and frequence of applications	Degree of control and effect on seedling growth
Milk of lime spray, 4 lbs. to 50 gallons of water	Leaves the size of a dime	Four applications a week apart	2% of plants infected
Zinc chloride ¼ oz. to a gal. of water applied a quart to a sq. yd.	At seedtime	Weekly after seed-leaf stage	No apparent infection: stunting and leaf injury
Copper acetate ½ oz. to a gal. of water applied a quart to a sq. yd.	At seedtime	Weekly after the seed-leaf stage	No apparent infection at transplanting; 16% primary infection in the field
Zinc sulphate-lime spray, 4–4–50 mixture	Seed-leaf stage	Four applications a week apart	No apparent infection at transplanting; 4% primary infection in the field.
Flotation sulphur spray, 23 grams of the sulphur to a gal. of water	Seed-leaf stage	Four applications a week apart	41% of the plants infected
Sodium-fluo-silicate 3½ grams to a sq. yd. in water suspension	Leaves the size of a dime	Four applications a week apart	Wildfire infection
Semesan 2 grams to a sq. yd.	Seed-leaf stage	Three applications 10 days apart	No infection but considerable stunting or growth retardation
Ethyl mercury phosphate, DuBay 738, 1½ grams to a sq. yd.	Seed-leaf stage	Three applications a week apart	Wildfire infection; leaf and growth injury
Mercury compound, DuBay 664, one gram to a sq. yd.	Leaves the size of a dime	Three applications 10 days apart	14% of plants infected
Mercury compound, DuBay 502, one gram to a sq. yd.	Leaves the size of a dime	Three applications 10 days apart	1.5% of the plants infected
Nugreen, mercury and fertilizer compound, 5 grams to a sq. yd.	Seed-leaf stage	Three applications 10 days apart	Wildfire infection; slight stunting
Check (a)	Contaminated as leaves were size of a dime	------------------	32% of the plants infected
Check (b)	Contamination at seedtime	------------------	53% of the plants infected
Check (c)	Contamination at seedtime	------------------	74% of the plants infected

in the season. That the disease does not survive in the soil itself for more than a brief time is shown by the tests reported here, and by other investigators (1, 16). The infections that were obtained by depositing in beds of tobacco seedlings quantities of old weathered roots, butts, and stems, some of which had been gathered from land plowed in the early fall, indicate that renewal of wildfire is made possible chiefly by incompletely decayed diseased tobacco plants. This evidence is supported by the fact that, thus far, proof has not been found that any wild plants near tobacco fields act as hosts for the organism. The contamination of other plants or materials by contact thus would occur only in the presence of tobacco.

The time of the year and the degree of maturity of the plant tissues doubtless affect the rapidity with which tobacco waste undergoes decay when incorporated with the soil. This, in turn, would influence the longevity of the bacteria and determine whether they survive until the next tobacco crop. Wildfire does not reappear in Lancaster county upon those seed-bed sites where tobacco plants not required for transplanting, together with vegetation in aisles or on adjacent ground, are all completely turned into the soil during the summer, when the tissues are green and succulent. In contrast, the most unsanitary seed-bed sites are those where young tobacco plants are left to grow to maturity; the ripened woody tissues are not completely decomposed between fall and the seed-bed period in spring.

Sources of Infection. A true index of the relative amount of wildfire that is derived from seed beds and from field sources respectively is difficult to obtain by a general disease survey, since secondary spread of infection tends to complicate the situation. Nearly all the infections that appear soon after transplanting are of seed-bed origin. In such cases, when there is an opportunity to examine the seed bed thoroughly, the source of disease usually can be ascertained definitely. There is scarcely an exception to the rule that field development of wildfire follows seed-bed infection, even though the disease spots in the seed bed are localized and limited in number.

Wildfire arising from over-wintering in the field may appear at any time from transplanting until fall, but may be difficult to distinguish because of possible secondary dissemination. The experimental data available indicate that the relative importance of the seed bed and the field as sources of infection varies greatly from year to year, but that seed-bed origin is always by far the more important. A survey of 50 farms in Lancaster county in 1931 (6) revealed that half of the seed beds had some wildfire. At cutting time, however, only 11 farms were free of disease. Thus there were 14 farms in which infection came either from over-wintering in the field or from neighboring land where infected seedlings had been set out. Since 1931 followed two very dry years, it is not probable that over-wintering in the field was very important unless wildfire had developed on unplowed infested fields during the previous fall. In 1931, severe wildfire losses occurred only where there was seed-bed infection. On the 14 farms where no seed-bed disease was observed, 2 fields suffered moderate losses of less than 10 per cent and 12 fields had a slight loss of less than 2 per cent.

Detailed data are lacking for 1932, but at least one-third of the seed beds exhibited wildfire, while at cutting time diseased fields were in the majority, as in the previous year. In 1933, only a small proportion of the seed-beds escaped wildfire because of a very wet May. Disastrous rainstorms during August, with 13.94 inches of precipitation, left scarcely a tobacco field in Lancaster county without severe damage by the disease.

The year 1934 was outstanding for the over-wintering of the wildfire organism under field conditions, as the 17 demonstrations of seed-bed control methods gave evidence. Probably the abundance and wide distribution of infected material in the field resulting from overflowing surface water the preceding year also was a factor.

In 1935, a survey of 60 farms in Lancaster county revealed 25 that had achieved disease-free seed-beds by sanitary and spraying measures, and 4 that had escaped disease although no special attempt had been made to control

wildfire. On the other 31 farms, seed-bed infection was observed and the respective fields all showed more or less severe wildfire damage. Of the 29 cases where seed-beds were clean, 9 fields showed slight wildfire infection at cutting time and 1 showed severe infection. In the latter case, the field had been contaminated at an early period by a power duster which had come directly from a diseased field. The slight infections appeared to be cases of contamination by tobacco stalks or washing from adjoining infected fields.

The two consecutive dry years of 1929 and 1930 did not effect any significant decrease in the proportion of farms or seed-beds having wildfire. Moisture conditions in seed beds are such that some slight infection is probable if the organism is present. Seed beds, particularly those in a permanent location with uncultivated aisles and surrounded by perennial vegetation, and equipped with old muslin or frames, appear to have been very important factors in harboring the disease and enabling it to carry over the dry seasons when there was practically no leaf spot in the fields (4). Seed beds, however, should be progressively less important in harboring wildfire as more farmers become thoroughly familiar with proper control measures and their effective application. The marked importance of applying bordeaux mixture soon enough to be really preventive, or not later than the seed-leaf stage of seedling growth, in order to gain any value at all from the procedure is impressively shown in Table 3. When effective spraying becomes a general practice, many faults of sanitation will be overcome.

The study of the degree in which wildfire lives over in the field (Table 1) presents a factor that has been discounted heretofore. This source of infection can be eliminated only by giving more attention to sanitation in the field. Means for hastening the decomposition of infected tobacco plants and waste should be considered. Plowing infected fields immediately after cutting the tobacco is likely to prove beneficial, although the experiments show that this will not be fully effective in preventing over-wintering. It would check the spread of wildfire on sucker growth during the fall and diminish the likelihood of infected waste being transported to land that has become disease-free through crop rotation.

Community Cooperation Desirable. The fact that wildfire carries over in the field a single year is not necessarily important, because the common farm practice in Lancaster county is a 4-year rotation. Since measures for preventing seed-bed infection are effective, if properly applied, and since tobacco is grown on the same land but once in four or more years, it might appear that a clear course for avoiding the disease is available, particularly since the wildfire organism has not been found viable within the host tissues, under any circumstances, during the third year following the harvest of an infected crop. But, unfortunately, such is not the case.

Experience has shown that it may be impractical to eliminate all sources of the disease, particularly when the human factor has such great weight in the proper application of control measures. Certain growers who have large farms, long rotations and isolated fields, and who are successful in growing healthy seedlings, should achieve practical control of wildfire, individually. The general prevalence of the disease, however, is not likely to be decisively decreased except as it is checked by adverse weather or other environmental conditions, or by a more unanimous community cooperation in seeking to control it than has yet been in evidence. This is particularly true of communities

of small farms, although concerted action in combating the disease would tend to offset this handicap. Decided progress in the suppression of wildfire is possible only when all farmers have disease-free seed beds, and plant only in fields in which the disease has died out during the growth of crops other than tobacco.

Changes in Cultural Practices. Lancaster county appears to possess peculiar features of climate, soil, culture, fertilization, or varieties of tobacco that favor the survival and development of the wildfire bacteria. Wildfire has appeared at times in most of the tobacco regions of North America but, except in Pennsylvania and Maryland, the disease has tended to be temporary, either disappearing or ceasing to be a serious problem. The decline of wildfire in these other regions probably is due more to unfavorable environmental conditions, than to the efficiency of combative measures by growers. It is possible, therefore, that changes in environmental factors or cultural practices in Lancaster county may help to control the disease, or render the crop less susceptible to it.

In a preliminary study of factors that possibly may influence the virulence of the disease in Lancaster county, the alkalinity of the soils of that county is being considered. According to D. E. Haley,[4] 50 per cent of the soils examined were alkaline, with a pH ranging from 7.1 to 8.0; 20 per cent were neutral or but slightly acid with a pH ranging from 6.7 to 7.0; 22 per cent were moderately acid, with a pH of 6.0 to 6.6, and only 8 per cent were strongly acid, with a pH of 5.3 to 5.9. In contrast, Anderson (2) reports that the tobacco soils of Connecticut (where wildfire is not a serious problem) have a pH of 5.2 or lower, for the most part. Experiments have shown that the tobacco plant normally is best adapted to an acid soil. The lower limit of the growth range of *Bacterium tabacum* in nutrient broth culture is close to pH 5.0, while growth is delayed beginning at pH 5.5. The distribution of wildfire in the past does not indicate that soil acidity would wholly prevent the occurrence of the disease, but it might shorten the life of the bacteria, and lessen primary infection in the field. Moreover, the nutrition of the tobacco plant and its resultant degree of susceptibility to the disease might be affected. The maintenance of soil fertility in Lancaster county tobacco fields is based largely on the extensive use of barnyard manure and lime. Alfalfa and clover in the rotation have promoted the use of large amounts of lime. This fertilizer practice, with a tendency towards excess nitrogen and low potassium has increased the weight of leaf tobacco, but its resistance to disease may have been lowered. These relationships are being investigated.

Summary

Leaf-spot damage to tobacco in Lancaster county, Pennsylvania, is caused mostly by wildfire *(Bacterium tabacum)*. The reddish-brown, zonated type of leaf-spot appearing after rainstorms and commonly known to farmers as "rust" is merely a manifestation of wildfire in which the characteristic yellow halo is lacking. It is doubtful if there are any non-parasitic leaf-spots, caused merely by wet weather. Angular leaf-spot *(Bacterium angulatum)* has not been found in this district.

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The commonly recommended method of wildfire control, based solely on disease-free seed beds, has failed to prevent the development of the disease in the field in all cases. Failure often is due to seed-bed practices that make the prevention of seedling infection difficult; but experiments for four years on isolated field plots have shown that wildfire bacteria, over-wintering under field conditions, also are an important source of the disease. Incompletely decayed parts of the tobacco plants, such as old butts, stalks, and sucker growth, are the chief materials that harbor the bacteria in the field. The disease survives at least a full year in the field and not more than two years under any condition of storage, as in tobacco barns. There is no evidence that the soil harbors the parasite provided the tobacco plant decays completely.

Search has not revealed any wild or cultivated plants that act as hosts of wildfire when tobacco is not grown in a field. Although the wild ground cherry, *Physalis virginiana,* which is a common roadside weed in Lancaster county, often has wildfire when growing near infected tobacco, no evidence of infection is found when this plant grows apart from tobacco.

Repeated experiments in allowing tobacco and potato flea beetles to feed upon wildfire-infected tobacco leaves have not shown that these insects disseminate the disease. The explanation appears to be that flea beetles are active during dry weather when conditions are not favorable for wildfire infection and when the susceptibility of tobacco is low.

Wildfire infection is markedly reduced when tobacco is grown under shade cloth. This appears to be due largely to the decrease of rain splashing and water soaking of leaf tissues.

The importance of making early application of fungicides in seed beds should be emphasized. Bordeaux mixture and copper lime dust may be applied with safety at seedtime. A loss of stand is caused only when the seed has been sprouted in bulk, but this may be offset by heavier sowing. Complete prevention of wildfire in contaminated beds is possible when the fungicides are applied at seedtime or at the seed-leaf stage.

A spray of calomel and milk powder mixed with water is as effective as bordeaux mixture in the prevention of wildfire in seed-beds. Calomel, however, may cause some stunting of the tobacco seedlings or a delay in the maturity of the crop, by preventing the development of secondary roots near the soil surface.

The over-wintering of wildfire bacteria under field conditions in Lancaster county is a factor in control that has not received the attention that it deserves. Danger from this source may be overcome by field sanitation and cultural practices that will hasten the decay of tobacco refuse. Since the wildfire organism does not survive in the field more than two years, under any conditions, the common 4-year tobacco rotation favors the control of the disease. Fall plowing does not completely prevent over-wintering but may prevent the spread of wildfire on sucker growth during the fall and the washing of infected refuse into clean fields by flowing surface water.

The amount of wildfire derived respectively from seed beds and field sources varies greatly from year to year; usually seed beds are much more important. In years of average rainfall, as in 1931 and 1935, severe losses are limited almost entirely to cases of seed-bed infection. Very wet years tend to increase the importance of over-wintering in the field and lead to the contamination of land on which tobacco is not being grown.

The prevalence of wildfire in Lancaster county indicates that climatic, soil and cultural conditions in that district especially favor the disease. Further research is required to determine whether the modification of some condition or cultural practice may not prevent the over-wintering of the parasite and reduce the susceptibility of the tobacco plant to the disease.

Success in combating wildfire in Lancaster county requires a high degree of community cooperation since many farms are small, neighboring sources of disease are often close at hand and the contour of the land favors the transportation of infected refuse by washing, in addition to other means of dissemination.

Control Recommendations

On the basis of the experimental evidence here presented the following measures for controlling tobacco wildfire are recommended:

1. A seed-bed location that is a safe distance from tobacco barns or any other source of infected tobacco.
2. The abandonment of locations that cannot be made sanitary by plowing after the transplanting season.
3. The sterilization of all equipment used in tobacco culture.
4. The early and thorough application of bordeaux mixture to the seedbed, commencing not later than the seed-leaf stage of seedling growth. The use of power sprayers will facilitate the application of the spray.
5. The prevention of the over-wintering of wildfire bacteria under field conditions by sanitation and cultural practices, including fall plowing, that will hasten the decay of tobacco refuse.
6. Community cooperation in control measures.

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